Tomosynthesis in a limited angular range

The invention relates to a method of forming an X-ray layer image of an object to be examined as disclosed in the introductory part of claim 1, and also to an X-ray device, notably intended for carrying out such a method, as disclosed in the introductory part of claim 13.

The formation of X-ray layer images of an object to be examined by utilizing tomosynthesis has been known since long. Initially the X-ray source and the X-ray detector were then displaced in opposite directions in planes extending parallel to the object to be examined and parallel to one another; X-ray projection images of the object to be examined were thus acquired from different positions. Using suitable reconstruction methods, layer images of layers of the object to be examined could be formed from such X-ray projection images, said layer images extending parallel to the planes in which the X-ray source and the X-ray detector were moved.

It is also known to move the X-ray source and the X-ray detector along circular trajectories around the object to be examined, for example, by means of a C-arm. Thus far it was assumed that a complete data set is necessary for the reconstruction of high quality layer images; for this purpose the X-ray source and the X-ray detector must be displaced through an angular range of at least 180° around the object to be examined. This condition was also imposed because layer images were to be formed not only in a single plane or in parallel planes through the object to be examined, but also in a plurality of preferably mutually perpendicular planes through the object to be examined.

It is an object of the present invention to provide a method of and a device for forming an X-ray layer image where an X-ray layer image of adequate image quality can be formed in a single plane or in mutually parallel planes while using fewer means or in a shorter period of time.

This object is achieved in accordance with the invention by means of a method as claimed in claim 1. The object is also achieved by means of an X-ray device as claimed in claim 13.

The invention is based on the idea that the formation of a layer image in a single plane or in parallel planes does not necessitate displacement of the X-ray source and

the X-ray detector through at least 180° around the object to be examined and that acquisition of X-ray projection images from an angular range of less than 180° suffices to form an X-ray layer image of adequate image quality. It is to be noted that it has been found in particular that artefacts occur to a limited extent only in an angular range of less than 180°; such artefacts can be ignored for clinical applications. This holds notably for an X-ray layer image that lies in a plane perpendicular to the bisector of the angular range in which the X-ray source and the X-ray detector are displaced so as to form the X-ray projection images. When use is made of a C-arm X-ray device, as in a preferred embodiment, the bisector thus corresponds quasi to the central position of the X-ray source which is pivoted in both directions by half the amount of the overall angle of the angular range in order to acquire the X-ray projection images.

Moreover, the X-ray layer images in accordance with the invention are calculated directly from the X-ray projection images, as opposed to the known methods where they are calculated from a 3D data set determined from the X-ray projection images.

Thus, in accordance with the invention X-ray layer images can be formed in parallel layers in a simple and fast manner, because the angular displacement range to be covered is smaller than in the known methods. On the other hand, the speed of rotation of the X-ray source and the X-ray detector may also be reduced and the period of time during which a contrast agent is present in the object to be examined can be used more effectively.

In a further version of the invention, the position of the angular range relative to the object to be examined can be changed so as to image differently oriented layers.

In preferred versions of the method in accordance with the invention the angular range amounts to from 90° to 180° or, in dependence on the relevant application, to even less than 90°. It has been found that an image quality that suffices for various clinical applications as well as adequate suppression of artefacts can also be achieved in the case of an angular range of less than 150°. However, it is to be noted that when the angular range is reduced further, contour lines of object details in the examination zone are become more and more blurred.

In order to reduce the time required for the acquisition of the X-ray projection images and the formation of the X-ray layer image even further, the number of X-ray projection images to be acquired for the formation of the X-ray layer image is limited in further preferred versions of the invention. Granted, the image quality generally becomes higher as the number of projection images is larger, because the reconstruction artefacts are spread better. However, it has been found that adequate image quality can be achieved

already by using a number of no more than 100 X-ray projection images; for specific applications a maximum number of 80 X-ray projection images even suffices. The reduction of the number of images also leads to a reduction of the radiation dose.

Furthermore, in a preferred version a plurality of essentially parallel X-ray layer images of the object to be examined are formed from the X-ray projection images acquired. This is possible because in accordance with the invention the image quality suffices for essentially parallel X-ray layer images, whereas the image quality of X-ray layer images of layers that are situated essentially parallel to the bisector would be significantly poorer and inadequate for clinical applications.

In accordance with the invention a C-arm X-ray device is advantageously used for the acquisition of the X-ray projection images.

It may also be advantageous to combine a plurality of X-ray layer images of neighboring thin layers so as to form an X-ray layer image of a thicker layer.

For the acquisition of the X-ray projection images the X-ray source and the X-ray detector can be displaced either along a circular trajectory or in an opposite sense in parallel planes, so in opposite directions around the object to be examined as in the case of the known tomosynthesis. Furthermore, it may also be arranged that only the X-ray source or only the X-ray detector is displaced in a single plane around the object to be examined while the other element is stationary.

The invention also relates to an X-ray device as claimed in claim 13 which may be further elaborated in the same or similar manner as the method in accordance with the invention as described above and hence have corresponding advantageous embodiments.

The invention will be described in detail hereinafter with reference to the drawing. Therein:

Fig. 1 shows a C-arm X-ray device in accordance with the invention;

Fig. 2 shows X-ray layer images of the point of the foot of a patient that have been formed by means of X-ray layer images from different angular ranges, and

Fig. 3 shows X-ray layer images of the point of the foot that have been formed from different numbers of X-ray projection images.

The X-ray device in accordance with the invention as shown in Fig. 1 includes a C-arm 1, the ends of which accommodate an X-ray source 2 and a facing X-ray detector 3, respectively. The C-arm 1 is suspended from an L-arm 5, by way of a pivot 4, so as to be rotatable about the horizontal propeller axis 12. The L-arm 5 is suspended from a displaceable carriage 7 by way of a further pivot 6; said carriage is suspended from the

ceiling 8. The pivot 6 enables rotation about the vertical axis 13. The L-arm 5 can be displaced in the horizontal direction by way of the carriage 7. An object 9 to be examined (symbolically shown), for example a patient, is arranged on a patient table 10 so as to be examined; said patient table is mounted on a base 11 whose height can be adjusted and which is also displaceable in the horizontal direction 19. A control unit 17 is for control of the X-ray device. The image processing, notably the formation of X-ray layer images from X-ray projection images acquired, is performed by means of an image processing unit 18.

For various clinical applications it is often necessary to form only a single X-ray layer image of a single layer S1 or a plurality of layer images of parallel layers S1, S2 of the object 9 to be examined. According to known methods first a complete three-dimensional data set of the region of interest of the object to be examined is acquired in order to calculate and reproduce one or more X-ray layer images therefrom by means of a suitable reconstruction method. For the acquisition of a complete three-dimensional data set, however, it is necessary to acquire X-ray projection images from a minimum range so as to satisfy the so-called condition of completeness. To this end it is necessary at least to acquire X-ray projection images from an angular range of at least 180°, which means that the X-ray source 2 and the X-ray detector 3 are rotated along a trajectory in the form of a half circle around the object 9 to be examined, for example around the propeller axis 12 or around an axis that extends perpendicularly to the plane of drawing and through the point of intersection of the axes 12 and 13. X-ray projection images are then acquired from different angular positions in order to extract the data for the three-dimensional data set therefrom. In order to obtain more data, above all trajectories in the form of two mutually perpendicular half circles or in the form of one or two mutually perpendicular full circles are proposed.

It has been found that such known methods have the drawback that the acquisition of the three-dimensional data set and the formation of one or more X-ray layer images therefrom require a comparatively long period of time. Moreover, it is often impossible to acquire all X-ray projection images during a single rotary motion of the C-arm 1; for example, in the case of trajectories in the form of two mutually perpendicular half circles it is necessary to interrupt the acquisition of the X-ray projection images after completion of the first half circle trajectory, to move the C-arm to the starting position of the second half circle trajectory, and to acquire the remaining X-ray projection images subsequently. This takes up an additional period of time and it is not possible either to execute this operation during a single injection with contrast agent that is required for given clinical applications.

However, it has been found that the expenditure for the acquisition of the X-ray projection images can be significantly reduced when it is only necessary to form a single X-ray layer image or a plurality of X-ray layer images of parallel layers. This is because in that case it suffices to acquire X-ray projection images from a limited angular range only, that is, an angular range smaller than 180°, and to determine the X-ray layer images therefrom. For example, when X-ray layer images of the layers S1 and S2 of the object 9 to be examined have to be formed, it suffices to acquire X-ray projection images exclusively from the angular range 14, which means that the C-arm 1 has to be displaced only between the starting position 15 and the final position 16; the X-ray projection images are acquired from different directions during such displacement. The angular range 14 is positioned in such a manner that the bisector 20 of this angular range 14 extends essentially perpendicularly to the layers S1 and S2 of interest. When X-ray layer images are to be formed for other layers that are not situated parallel to the layer S1, the angular range 14 is positioned accordingly so that the bisector again extends essentially perpendicularly to these layers. Layer images of layers that do not extend exactly perpendicularly to the bisector 20 can also be formed from the X-ray projection images acquired, the image quality, however, then becomes poorer as the deviation relative to the perpendicular position is larger.

In accordance with the invention the X-ray layer images are calculated from the acquired X-ray projection images by tomosynthesis while utilizing a suitable reconstruction method, for example the Feldkamp algorithm or partial backprojection. The X-ray layer images are then formed directly from the X-ray projection images, that is, without a detour via the formation of a three-dimensional data set as in the known methods. In accordance with the invention the angular range 14 amounts to less than 180° and can be reduced even further in dependence on the relevant application and the desired image quality.

In a practical application X-ray layer images were formed of the point of the foot of a patient while reducing the angular range all the time. The results are shown in Fig. 2. The gaps between the toe bones (arrowhead) is clearly visible in the lower two images whereas in the upper two images, formed from X-ray projection images from an angular range of 91° and 120°, respectively, the resolution is more blurred and the boundaries of the elements shown are no longer visible so clearly. The artefacts, however, are negligibly small in all four images.

In accordance with the invention it has also been found that the number of X-ray projection images for forming an X-ray layer image can be reduced in comparison with the known method. For example, in one application X-ray layer images of the point of the

foot were acquired with 36, 60, 80 and 100 X-ray projection images from each time an angular range of 180° and respective X-ray layer images were formed therefrom The results are shown in Fig. 3. It is to be noted that the resolution and the effects of artefacts are acceptable in the lower two layer images (n = 80, n = 100), whereas the artefacts are too pronounced in the upper two images. For clinical applications, however, the X-ray layer image that has been formed from 80 X-ray projection images may also suffice. Additionally, the angular range can be suitably chosen as enabled by the C-arm X-ray device shown.

It is to be emphasized again that the invention is not restricted to the embodiment shown. It is notably possible to arrange the X-ray source and the X-ray detector, instead of on a C-arm, in parallel planes relative to one another while using a suitable mechanical system, the object to be examined then being situated between said planes. The X-ray ray source and the X-ray detector are preferably moved in opposite directions in such an arrangement, so that the projection lines, that is, the connecting lines between the X-ray source and the X-ray detector, always intersect in the examination zone. Moreover, it may be arranged that only the X-ray detector is moved or only the X-ray source.